Chapter 25
Mechanical Performance of Fly Ash Geopolymeric Mortars Containing Phase Change Materials

M. Kheradmand, Z. Abdollahnejad, and F. Pacheco Torgal

European Union (EU) aims to achieve nearly zero-energy (public) building (NZEB) by the end of 2018. This very ambitious target would be more easily fulfilled if high-thermal performance materials like phase change materials (PCMs) are to be used. This paper reports experimental results on the mechanical properties of geopolymeric mortars containing PCMs at ambient temperature and after exposure to high temperature. The results show that the inclusion of PCMs is responsible for a reduction of the mechanical strength of the mortars. Several mixtures showed an increase in compressive strength after being exposed to high temperatures. Since PCMs are made of flammable materials, geopolymeric mortars are more advantageous than Portland cement-based mortars for PCM incorporation.

1 Introduction

Global warming is considered one of the worst problems faced by our planet, and the production of energy is considered to be the first responsible for that problem [1].

Buildings are a major contributor for carbon dioxide emissions, and higher energy efficiency levels are required [2]. Building energy efficiency will not only be able to cut carbon dioxide emissions but also create new jobs [3]. In this context the European Energy Performance of Buildings Directive 2002/91/EC represents a step forward by defining very ambitious requirements for buildings [4]. Accordingly

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M. Kheradmand · Z. Abdollahnejad
University of Minho, Gumarães, Portugal

F. Pacheco Torgal (✉)
University of Minho, Gumarães, Portugal

University of Sungkyunkwan, Suwon, Republic of Korea
e-mail: torgal@civil.uminho.pt

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by January 1 of 2021, all new private buildings must be of the nearly zero-energy type. For public buildings the requirement is even more ambitious and sets January 1 of 2019 as the deadline. For such targets to be met, new and improved materials will be needed. This is the case of PCMs [5] that use chemical bonds to store or release heat hence reducing energy consumption. PCMs can absorb heat inside buildings avoiding excessive heating and reducing cooling needs. Also the European agenda regarding resource efficiency requires that waste is to be managed as a resource [6]. This is a very important goal in the European context of a circular economy and zero-waste target [7]. Thus materials that have the ability for the reuse of several types of wastes such as geopolymers are to deserve a special attention from the scientific community [8, 9]. This is the case of fly ash [10]. In this context this paper reports experimental results on the properties of fly ash geopolymeric mortars containing PCMs and different ratios of activator/binder and sodium silicate/ sodium hydroxide.

2 Experimental Programme

The binder precursor was composed by 90% of fly ash and 10% calcium hydroxide. This is because previous investigations show that calcium hydroxide is crucial for the durability of geopolymers [11] and that some authors reported that 10% is an optimum amount [12]. Solid sodium hydroxide, which was obtained from commer- AU1 cially available product of Ercros, SA, Spain, was used to prepare the 12 M NaOH solution. The chemical composition of the sodium hydroxide was 25% Na_2O and 75% H_2O. The sodium silicate liquid was supplied by MARCANDE, Portugal. The chemical composition of the sodium silicate was of 13.5% Na_2O, 58.7% SiO_2 and 45.2% H_2O. The fly ash was obtained from the PEGO Thermal Power Plant in Portugal, and it was classified as class F according to ASTM-C618 [13] standard. It was used as the base material for the production of the geopolymers. The chemical composition of the fly ash is presented in Table 25.1.

The adopted for the mortars are Portland cement type I class 42.5R from Secil, Portugal, and calcium hydroxide from Lusical H100. In terms of chemical components, OPC contains 63.3% CaO, 21.4%SiO_2, 4.0%Fe_2O, 3.3%Al_2O_3, 2.4%MgO and other components. The calcium hydroxide used in this study contains more than 99% CaO. The sand was used as inert filler provided from the MIBAL, Minas de AU2 Barqueiros, SA, Portugal, in which they are passing from 4.75 mm sieve and remaining on 0.6 mm sieve. The altered sieve was used in order to remove dusts from the sand particles. The superplasticizer was commercially available in polyacrylate from Acronal series, with a density of 1050 kg.m^3 from BASF. One

Table 25.1 Major oxides in fly ash

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2
60.8	22.7	7.6	1.0	2.2	1.5	2.7	1.5

Table 25.2 Properties of PCMs

Operating temperature range	Latent heat of fusion (J/g)	Melting point (°C)	Apparent density at solid state (kg/m^3)	Particle size distribution range (μm)
60.8	22.7	7.6	1.0	2.2

type of organic microencapsulated PCM was considered: BSF26 with a melting temperature of 26 °C. The properties of the selected PCM for this study are provided by the manufacturer and are presented in Table 25.2.

Geopolymer specimens were prepared with respect to the following steps: (i) homogenization of sodium silicate and NaOH solution (12 M) for 1 min, (ii) mixing all the solid materials together by using standard mortar mixture upon speed I (65 rpm) for 3 min and (iii) addition of solution into the blends and mixture for 1 min with speed I (65 rpm) and another 1 min with speed II (90 rpm). Then the mixture was transferred to metallic moulds. After nearly 4 h, the specimens were demoulded and kept sealed with the plastic wrap and then left in the same curing conditions until the date of testing. The specimens were cured in laboratory conditions (25 °C and 65%RH). Compressive strength testing was carried out at 7, 14 and 28 days with respect to the recommendations of the European standard EN1015–1. In order to determine the compressive strength of the mortars, a total number of six specimens were used for each mortar mix in which two specimens were tested at proposed ages of testing. The specimens used for compressive strength had 50 mm × 50 mm × 50 mm. A second series of the specimens with 28 days of curing were tested for compressive strength after being exposed to high temperature (200 °C and 600 °C) during 4 h. Next, the specimens were cooled down lasting about 12 h. at room temperature, and immediately the compressive tests were performed (following the above curing/testing procedure). Then the specimens were kept sealed with a plastic wrap under at laboratory environment until testing date of 7 days, 14 days and 28 days. After that, the compressive strength measurements were carried out through a compressive strength apparatus model LLOYD-LR50KPlus with the capacity of 50kN.

3 Results and Discussion

The results of the compressive strength are shown in Fig. 25.1. The increase of PCM incorporation resulted in a decrease of compressive strength from ≈16 MPa to ≈4 MPa at 28 days. It can also be observed that there is a noticeable difference in changes of compressive strength with addition of different amount of PCM when compared to reference specimens (without PCM), particularly at 14 and 28 days. PCMs exhibit little effect of compressive strength at 7 days.

Previous studies [14] show that the PCM incorporation in the mortars increases porosity of specimens. Furthermore, increasing of curing ages has always enhanced

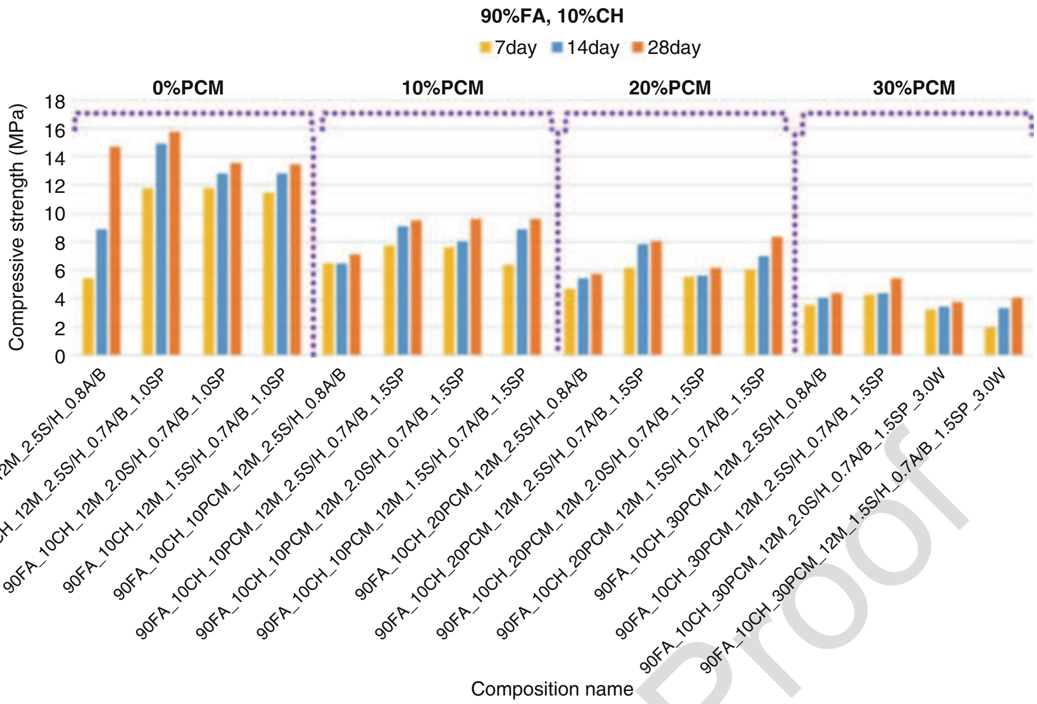

Fig. 25.1 Compressive strength of geopolymeric mortars

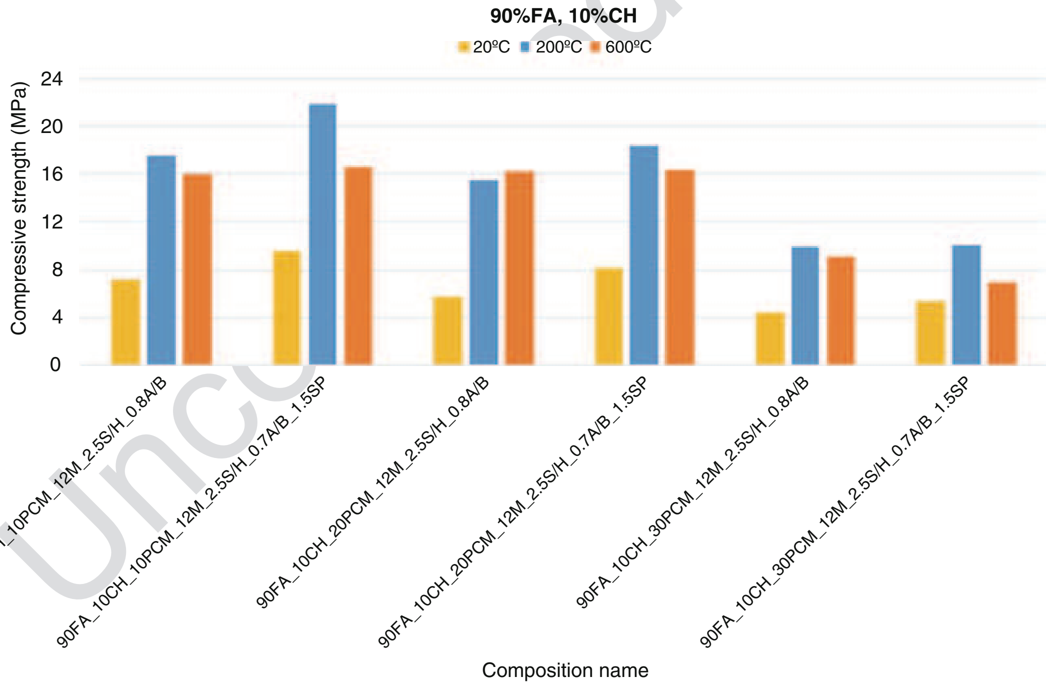

Fig. 25.2 Compressive strength of geopolymeric mortars exposed to high temperature

the compressive strength. Interestingly, compressive strength at 14 and 28 days is almost similar in most of the cases which is typical of sodium silicate-based geopolymeric mixtures. Figure 25.2 shows the compressive strength results of PCM-based mortars after being exposed to high temperatures. The difference between the strength at temperature of 20 °C and temperature of 200 °C is quite significant. In mixtures with 90%FA and 10%CH, the compressive strength is 60% higher than that of the strength of specimens at temperature of 20 °C. The mixtures with 90%FA and 10%CH when exposed to a temperature of 600 °C still showed an improvement in its compressive strength higher than 50%; however, it is slightly lower than the compressive strength of reference specimens when exposed to a temperature of 600 °C. Several authors present different explanations for the strength increase of geopolymers exposed to a high temperature. Some state that the strength increase is attributed to a combination of polymerization reaction and the sintering reactions of unreacted fly ash particles [15, 16]. More recently others attributed the strength increase to promotion of polycondensation between chain-like geopolymer gels [17]. As to the compressive strength reduction of mixtures exposed to a temperature of 600 °C, it can be maybe due to thermal incompatibility arising from nonuniform temperature distribution as suggested by others [18, 19]. Geopolymeric mortars with PCM do not show any destruction of the specimens after exposing to the high temperatures. This finding constitutes an important advantage of the PCM geopolymeric mortar when compared with conventional Portland cement-based PCM mortars because other authors [20] noticed that the PCM-based mortars can be destroyed upon high temperature expositions. Since PCMs are made by flammable materials, this means that geopolymeric mortars are in fact preferable to Portland cement-based mortars for PCM incorporation.

4 Conclusions

The inclusion of PCMs is responsible for a serious reduction of the mechanical strength of the geopolymeric mortars from ≈16 MPa to ≈4 MPa. Several mixtures showed an increase in compressive strength after being exposed to high temperatures. This strength increase may be attributed to a combination of polymerization reaction and the sintering reactions of unreacted fly ash particle or due to the polycondensation between chain-like geopolymer gels. Since PCMs are made of flammable materials, geopolymeric mortars are more advantageous than Portland cement-based mortars for PCM incorporation.

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